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PATENT & TRADEMARK OFFICE

Attorney's Docket No.: 10004405-1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : Duane Fasen et al.
Serial No. : 09/938,394
Filed : August 23, 2001
Title : BOTTOM ANTIREFLECTION COATING COLOR FILTER PROCESS FOR FABRICATING SOLID STATE IMAGE SENSORS

Art Unit : 2826
Examiner : Mandala, Victor A

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER 37 CFR § 1.131

We, Duane Fasen, Jack D. Meyer, Cheryl Bailey, John H. Stanback, and Kari Hansen, hereby declare as follows.

1. We are the inventors of the subject matter recited in the pending claims of the above-identified patent application.

2. Prior to July 13, 2001, we completed our invention as described and claimed in the subject application in this country, as evidenced by the following.

a. Prior to July 13, 2001, we conceived the idea of an image sensor system that included: an active image sensing device structure having an array of light sensing elements; a color filter array having an array of color filters each disposed over a respective light sensing element, wherein light travels from each color filter to a respective light sensing element through a respective light transmission path substantially transmissive to radiation in a visible wavelength range; and a bottom antireflection coating disposed in each light transmission path between the the color filter array and the active image sensing device structure.

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as First Class Mail in an envelope addressed to: Commissioner for Patents, PO Box 1450, Alexandria, VA 22313-1450 on:

February 17, 2004
Date

(Signature of person mailing papers)

Edouard Garcia
(Typed or printed name of person mailing papers)

b. Prior to July 13, 2001, we made physical embodiments of the image sensor system of ¶ 2.a and we tested these physical embodiments in a manner demonstrative of the workability of the idea of ¶ 2.a.

c. The reduction to practice of the physical embodiments of ¶ 2.b is evidenced by the pages attached hereto as Exhibit A. The pages of Exhibit A numbered 10 and 11 diagrammatically show a portion of an image sensor embodiment of ¶2.b in which a 60 nm BARC layer is disposed between a color filter (labeled "Color resist" in page 11) and an active image sensing device structure. The page of Exhibit A numbered 17 shows the results (i.e., the plots labeled "BARC") of sensitivity tests that were performed on physical embodiments of the image sensor system of ¶ 2.b prior to July 13, 2001. Each of the pages of Exhibit A is dated prior to July 13, 2001.

d. The reduction to practice of the physical embodiments of ¶ 2.b also is evidenced by the document entitled "Kerosene Color Filter Process", which is attached hereto as Exhibit B. This document was prepared prior to July 13, 2001. This document describes the process by which embodiments of the image sensor system of ¶ 2.a were made prior to July 13, 2001. This document also describes the results of transmission and sensitivity tests that were performed on these embodiments prior to July 13, 2001.

3. Each of the dates deleted from Exhibits A and B is prior to July 13, 2001.

4. We declare that all statements made herein of our own knowledge are true and that all statements made on declaration and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Respectfully submitted,

Date: 2/12/2004

Duane Fasen

Date: 2/13/2004

Jack D. Meyer

Jack D. Meyer

Date: 13 February 04

Cheryl Bailey
Cheryl Bailey

Date: 2-14-2004

John H. Stanback

John H. Stanback

Date: 2/11/04

Kari Hansen

Attorney's Docket No.: 10004405-1

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EXHIBIT A

CERTIFICATE OF MAILING

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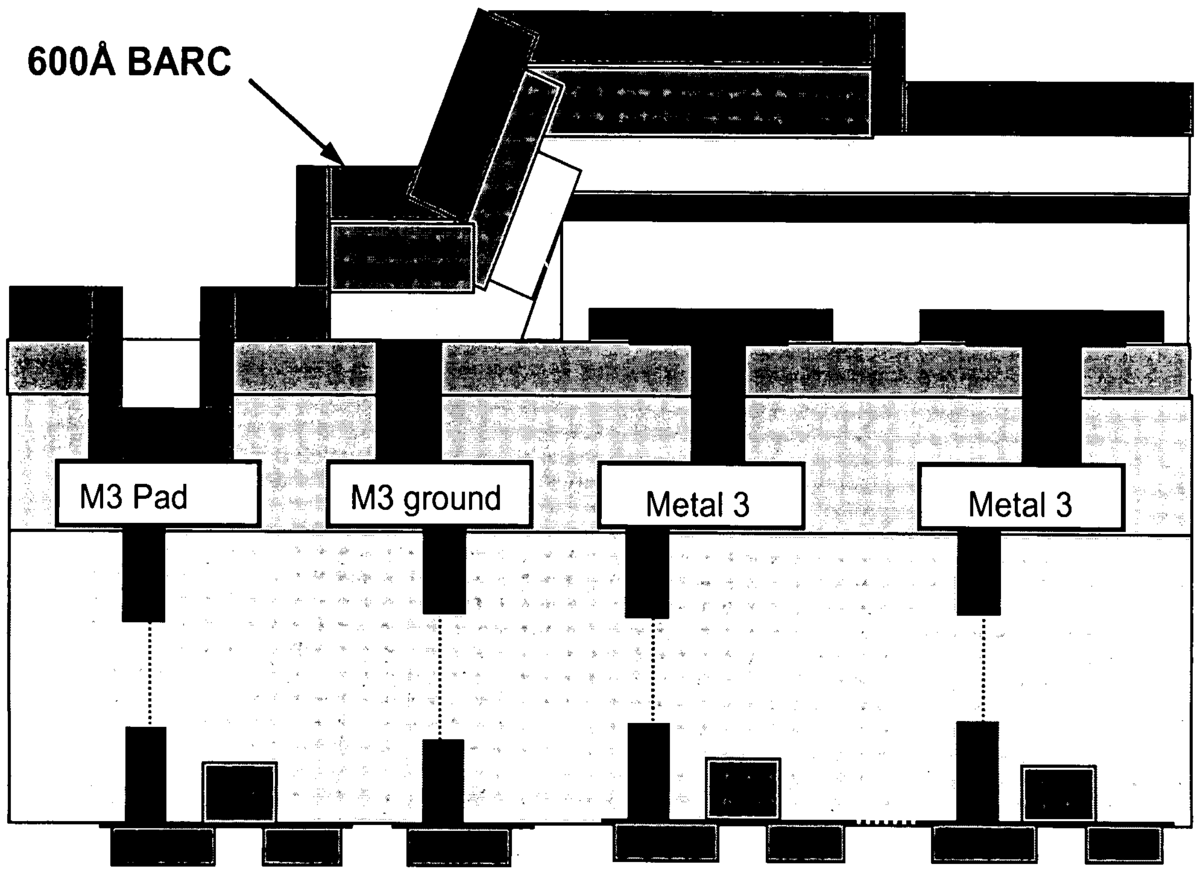
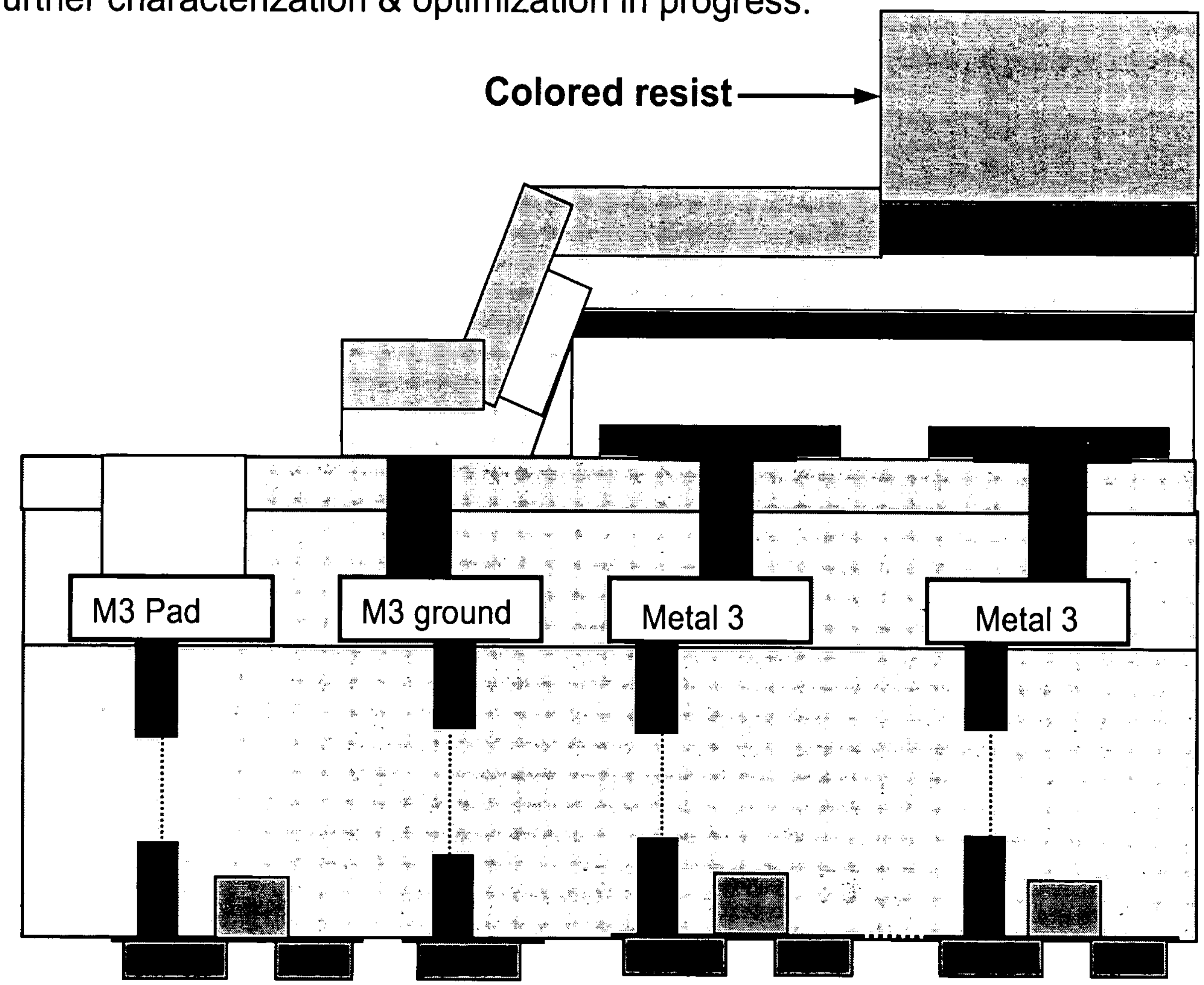
BARC application

- ~600Å thickness (standard DUV process.)
- Improves transmission in blue & green and improves colored resist adhesion to W & ITO.
- Eliminates developer attack of ITO and pad aluminum.

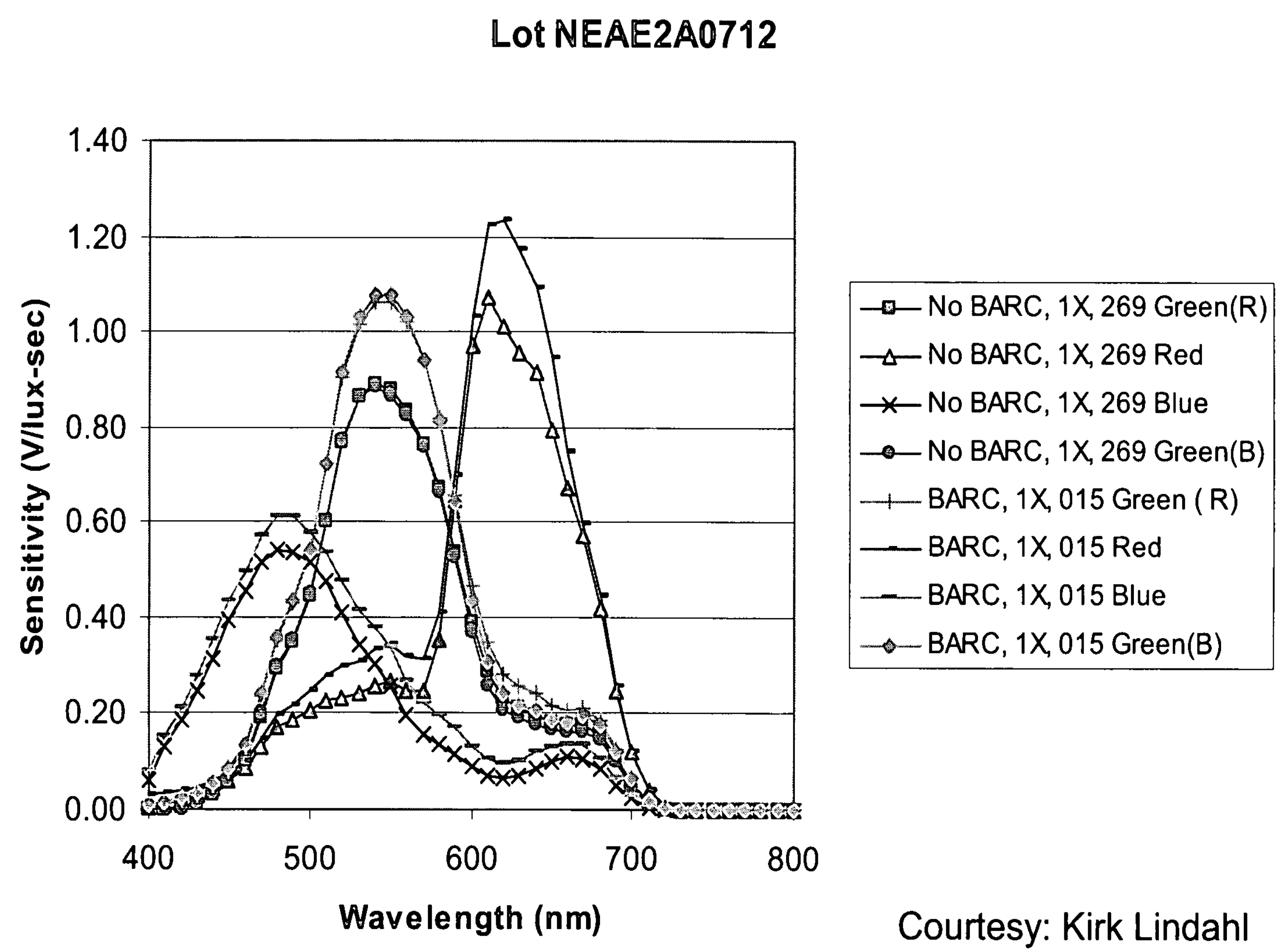


Colored resist definition

- Identical thickness and similar processing to bulk sensor products.
- Low power He/O_2 ash used to remove BARC.
- Further characterization & optimization in progress.



Sensitivity



Courtesy: Kirk Lindahl

Attorney's Docket No.: 10004405-1

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EXHIBIT B

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Edouard Garcia
(Typed or printed name of person mailing papers)

Kerosene Color Filter Process

BARC Process Details, [redacted]

Duane Fasen

Executive Summary

Significant improvements were made to the original Kerosene color filter resist process during [redacted]. For example, by modifying the blue develop cycle, ITO damage was largely eliminated. This resulted in increased blue and green transmission and reduced variability. However some photolithographic process margins were still insufficient for production release. Another solution was needed and the introduction of a DUV BARC layer was explored.

The addition of DUV BARC to the color filter process has consistently demonstrated superior pixel characteristics. As a consequence, the DUV BARC process has been adopted as the Plan Of Record (POR) process. The primary focus of this report is an assessment of data supporting the conversion to the DUV BARC process for Kerosene. In addition there is a discussion regarding alignment decisions, biasing, and other issues that have a bearing on release to production.

A. BARC Process Details

The DUV BARC process itself is a simple process modification to the color filter resist process used for the non-Kerosene process. Prior to the application of the colored resists, wafers are coated with 600A of DUV BARC on a DNS track. This BARC layer then receives a 60sec proximity bake at 205C.

Following patterning of red, blue, and green resists, removal of the BARC layer is required. This removal is currently performed by an ash in the LAM590. The ash is a buffered oxygen ash at low power to minimize unwanted removal of the color filter layers. It is possible that the ash could be further optimized.

BARC Application: Shipley AR2-600, 2000rpm dispense, 4790rpm spread
BARC Removal: 900mT, 40 sccm O2, 200 sccm He, -35V, 50W, 60 sec

It is probable that most any BARC of about 600A could be used in place of the Shipley product used here. As such the term BARC is used interchangeably with DUV BARC for the remainder of this paper.

B. Photolithography Process Improvements with BARC

Patterning improvements with the BARC process are significant. First, it eliminates several photo process problems. Color filter resist lifting is eliminated due to the blanket of organic BARC. Also eliminated are ITO (Indium Tin Oxide) and

bonding pad attack by the repeated application 4-50 developer and subsequence DI water rinses. The use of BARC also significantly reduced scumming at pixel edges and residue in open areas of the pixel array. This improvement may be due to a reduction in scattered light that serves to partially cross link the resist at feature edges or in the field areas.

In addition to solving photo process problems, the BARC process presents several advantages. Because of the reduction in scumming, the process exhibits greater resolution. When process margin (and the impact on array performance) is better understood, we may find that the DUV BARC process allows patterning pixel sizes at or below 3 microns in size. This process also allows for greater use of tungsten dark metal for either blocking light at pixel borders or surrounding the pixel array.

BARC removal cleans up much of the resist residue in the field areas. As the last step before parameter test, it also servers as a good bonding pad clean.

The BARC process does introduce an application and removal process step. However the improved process margin described above, together with transmission improvements discussed below, justify the minimal additional processing cost.

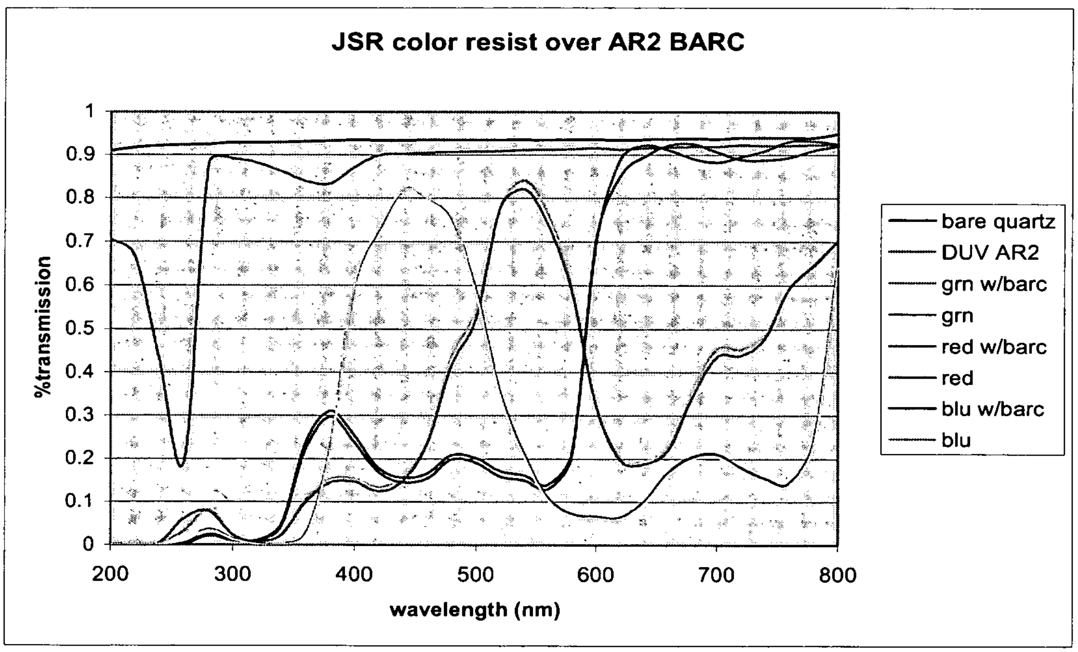

Figure 1: Transmission on Quartz with and without BARC

Agilent Restricted

C. R-B-G Transmission Improvements with BARC

Measurements show that the DUV BARC, by itself, is responsible for a transmission reduction of less than 2% as measured on quartz wafers for all resist colors. See Figure 1. However, there are two offsetting effects that more than make up for this nominal transmission reduction. First, the *application* of BARC results in greater transmission through the ITO – amorphous Silicon interface. Second, the *removal* of the BARC layer cleans the surface of the color filter resists.

Transmission Modeling

A thin film modeling program called TFCalc was used in an attempt to model the characteristics of the Kerosene optical stack, with and without BARC of varying thicknesses. Rick Snyder provided a model for amorphous silicon capped by a piecewise representation of ITO. He also provided models for the colored resists. Each of these was empirically derived by J.A. Woollam Company from sample wafers produced in this fab.

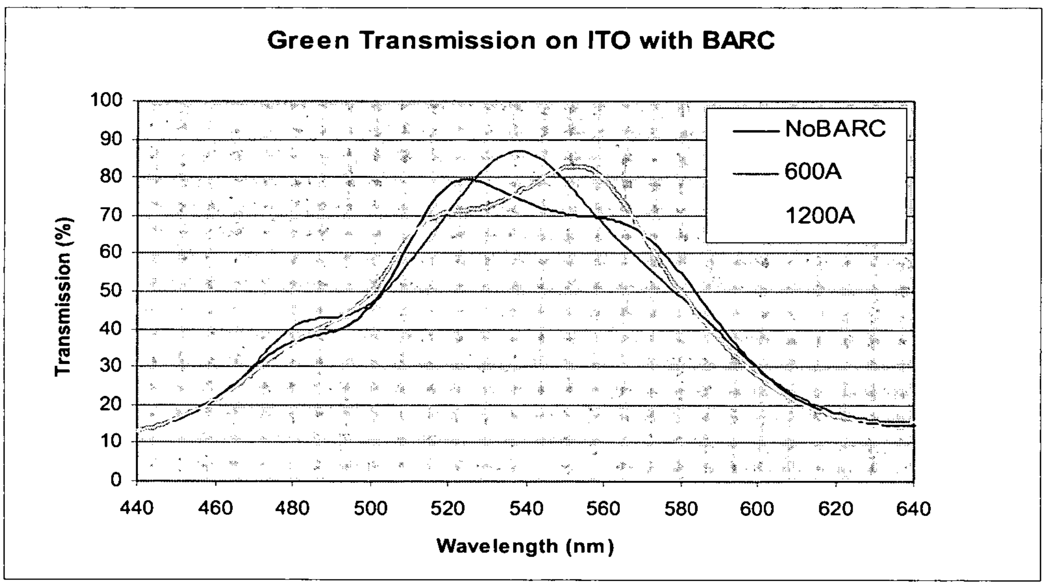

Figure 2: Modeled green transmission with varying BARC thickness

The film stack was then modeled with and without BARC, followed by roughly 10,000A of colored resist. The index of refraction of BARC was taken from published Cauchy coefficients, the extinction coefficient was set to zero. Single layer representations were used for red and blue. A five layer representation was used for green resist.

Figure 2 shows transmission into the amorphous silicon substrate, with BARC thickness of 0, 600, and 1200A. The peak transmission rolls across 540 nm as

BARC is introduced and then increased in thickness. Note also that the *peak* transmission magnitude increases by about 5%. But right at 540nm, the difference may be as much as 10% for 600A BARC.

In each case (red, blue, green), the effect of 600A BARC is to shift the transmission peak to better align with the wavelength of peak pixel sensitivity exhibited by packaged parts. For red and green, there is also a 5 to 10% increase in magnitude of that transmission peak. This result suggests slightly more transmission improvement for red and green relative to blue.

While the optimal BARC thickness varied slightly for the three colors, 600A is a good compromise thickness. In each case, the model predicts better optical transmission when AR2-600 BARC layer is introduced. When the BARC thickness is fixed at 600A, the optimal color filter thicknesses at 460 (blue), 540 (green), and 620nm (red) are 945, 1000, and 910nm, respectively. In practice, this is the approximate relative thickness of the color filter process as it currently exists.

TFCalc modeling also facilitates resist thickness sensitivity analysis. As expected, the rotation of the peak transmission exhibited in Figure 1 is cyclic. The same plot is generated each time the BARC thickness is increased by an amount that is 0.31 times the center wavelength (red, blue, or green). The same is true for the color filter thickness.

Resist thickness changes on quartz result in little or no change in the transmission simulation. However, the interference effect demonstrated by TFCalc suggests that shifts in thickness can result in significant changes in transmission into the amorphous silicon. Therefore, to hold tight color ratio performance, control of resist thickness should emphasized and be held to less than 2%.

Application of the modeling results should be tempered by an awareness of the actual physical characteristics of pixels in an array. For example, there is no single resist thickness for any given pixel; red, blue, or green. Conventional resist thickness varies lot to lot and wafer to wafer as in the case of any resist process. This is no different for color filter resists. In the case of color filter processing, however, there is a thickness variation across every pixel as well. This is due to resist flow during hard bake. It is probably more accurate to think in terms of an average thickness across each pixel.

More work could and probably should be done to verify the accuracy of the TFCalc modeling. However time and resource constraints will limit further investigation unless specific problems need to be addressed.

Quartz Wafer Studies

Previous attempts to clean bonding pads with a light ash have resulted in unwanted shifts in the red/green color ratio on the non-Kerosene process. It was speculated that red resist was being stained by subsequent color resist processing and that an ash could remove this top, stained layer. But this was never demonstrated. One would expect red resist to show the most evidence of staining because it is applied first and is then followed by the application and removal of both blue and green. Blue would also see an effect, but to a lesser degree.

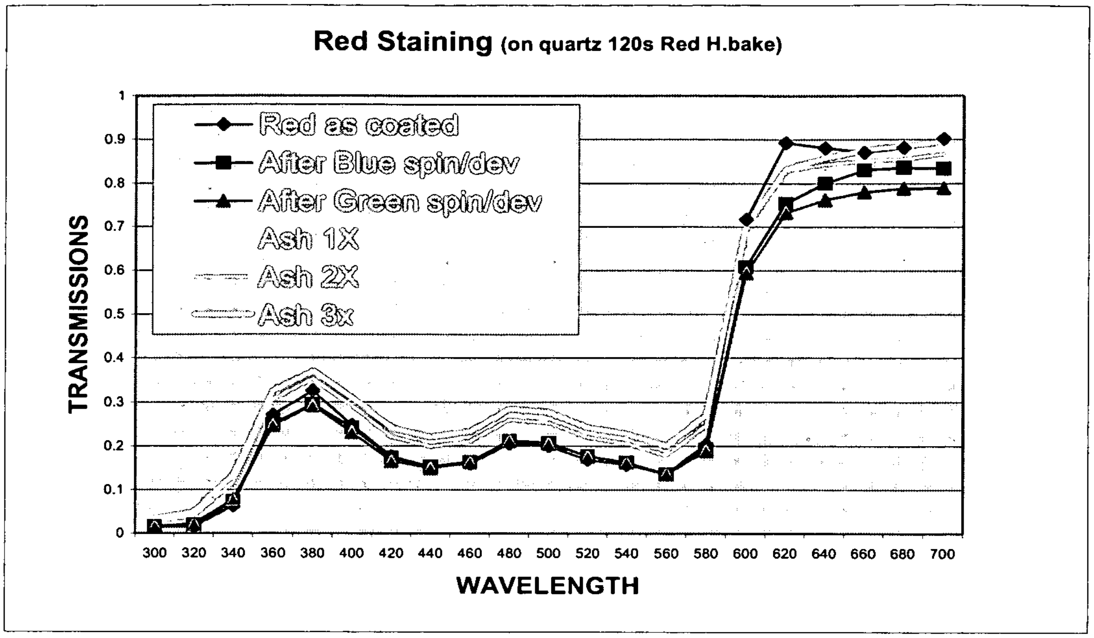

Figure 3: Red resist staining and clean-up by BARC removal ash

To simulate this effect, experiments were designed to look at the change in light transmission through quartz wafers coated with red resist only (no BARC). Quartz wafers are a reasonably close approximation to silicon substrates if additional time is allowed during the hard bake cycle. Figure 3 shows the full spectral behavior, starting with the quartz wafer immediately after red coat and hard bake. The blue and green curves show the reduction in transmission above 600nm *after application and removal* of blue and green resist, respectively. Similar tests demonstrated that the developer by itself does not reduce red transmission and that red does not stain red.

Next, the BARC removal ash was performed three times. Transmission data was obtained after each ash. Figure 3 shows a progressive increase in red resist transmission. On patterned wafers, roughly 700 angstroms is removed in a single ash. Since the quartz wafer is unpatterned, the removal rate is probably much lower, so the ash was repeated.

These studies provide a strong argument that red resist is being stained by subsequent color filter processing. This staining is likely happening on blue resist as well, but to a lesser degree. The effect is probably common to both Kerosene or bulk pixel process. The BARC removal in the Kerosene process has serendipitous effect of cleaning the red resist surface and boosting transmission.

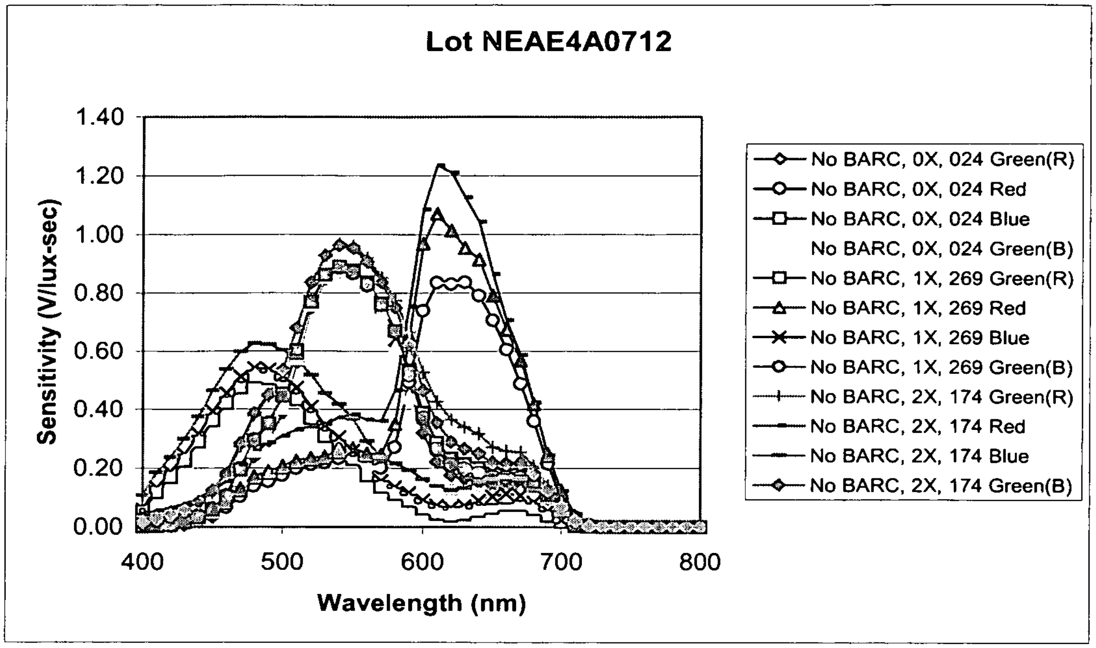

Figure 4: Effect of BARC removal on staining and transmission

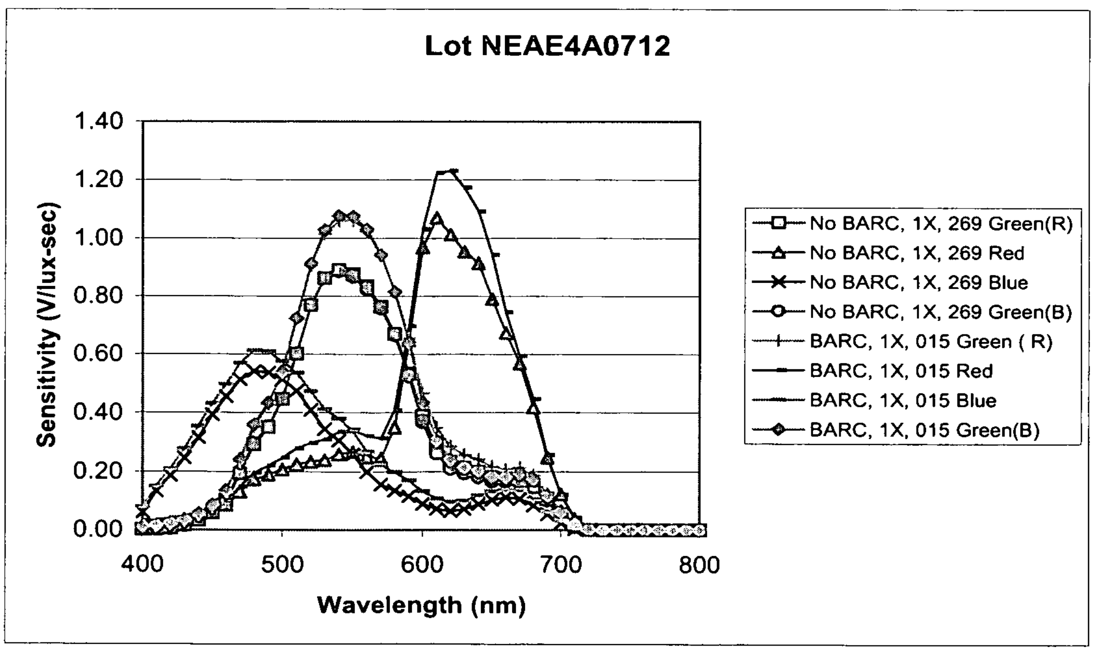

Figure 5: Transmission comparison with and without BARC

Packaged Part Studies

Results of TFCalc modeling and quartz wafer studies presented above is supported by data obtained by Kirk Lindahl on packaged parts. Figure 4 shows the effect of ashing Kerosene parts. These parts did not get the BARC process, in order to deconvolve some of the transmission effects. The first (1X) ash leads to no increase in green transmission, a slight increase in blue transmission, but a 20% increase in red transmission! This result would be consistent with the understanding that a stained layer is being removed from red (primarily) and blue resists by the BARC removal ash. Note that with the first ash, there is very little increase in transmissions in wavelengths that should be blocked by each resist.

The second (2X) ash increases the transmission for all 3 resist colors. This result is likely due to additional thinning of the non-stained resist coating and/or changes in interference due to that thinning. There may also be some additional removal of red resist staining in the second ash.

The undesirable side effect of the 2X ash is to allow additional transmission of the respective "off peak" wavelengths. For example, follow the red resist curve to about 540nm. The green light transmission in the red pixel has increased by more than 50%. The same effect is observed for blue and green resist as well.

It would appear then that the current ash is near optimal. Other tests showed the thickness reduction to be about 700A. Any less ashing and some of the stained layer on the red resist may be left. More ashing and the off target wavelength transmission increases unacceptably.

Figure 5 shows data comparing parts with and without BARC. This data lends empirical validation to the results of the TFCalc modeling discussed above. These parts each received a 1X ash, thereby removing the bulk of the staining effects. Still, in each case there is the predicted increase in transmission due to the introduction of the 600A BARC layer. TFCalc modeling also suggests that the increase in red and green might be greater than for blue resist.

Wafer Level Studies

Optical testing at wafer level produced results that are somewhat at odds with the model supported by the above discussion. Like the preceding results, transmission increases are seen on the order of the 20% when BARC is used. However, the primary cause appears to be the ashing, producing a similar improvement in all 3 colors. But packaged parts show significant improvement for red and blue only; not green.

Furthermore, the ashing effect dominates the BARC v.s. no BARC signal. This is also at odds with the results presented above. There is currently no explanation for this wafer level data. If resources exist, more packaged parts will be tested in order to gain more confidence in packaged part data.

F. Resist Surface Characteristics

Studies were completed to examine the change in resist surface characteristics at each step in the color filter process. As an example, Figures 6, 7, and 8 show changes

observed in the red resist surface from first application through BARC removal ash. A small library of photos exist but are not presented here. However, some of the lessons learned are:

- Color filter resist thickness, red in particular, is affected significantly by large topology steps in close proximity (~50u).
- Color filter resist surfaces are fairly smooth after deposition and hard bake.
- These surfaces become more "lumpy" with subsequent applications of resist, due to additional residue or some form of developer decoration of pigments.
- BARC ash removes residue in the field and on resist areas, and changes the surface appearance of the pixel yet again.

Having these photos, together with other supporting data, should provide a good baseline should we decide it is necessary to change the BARC removal ash at a later date.

Acknowledgements

Linda Caldwell and Cheryl Bailey performed most experiments in the fab. Their work is greatly appreciated. I would also like to thank Rick Snyder for his assistance with the TFCalc modeling and for his library models of various elements in the kerosene film stack. Kirk Lindahl also contributed significantly by the data presented from packaged parts.

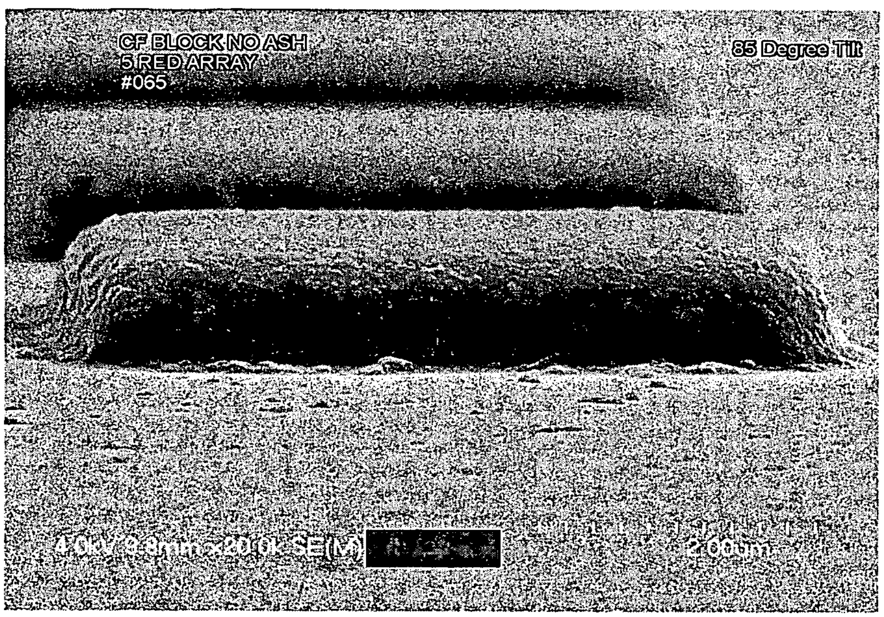

Figure 6: Red resist after pattern and hard bake only

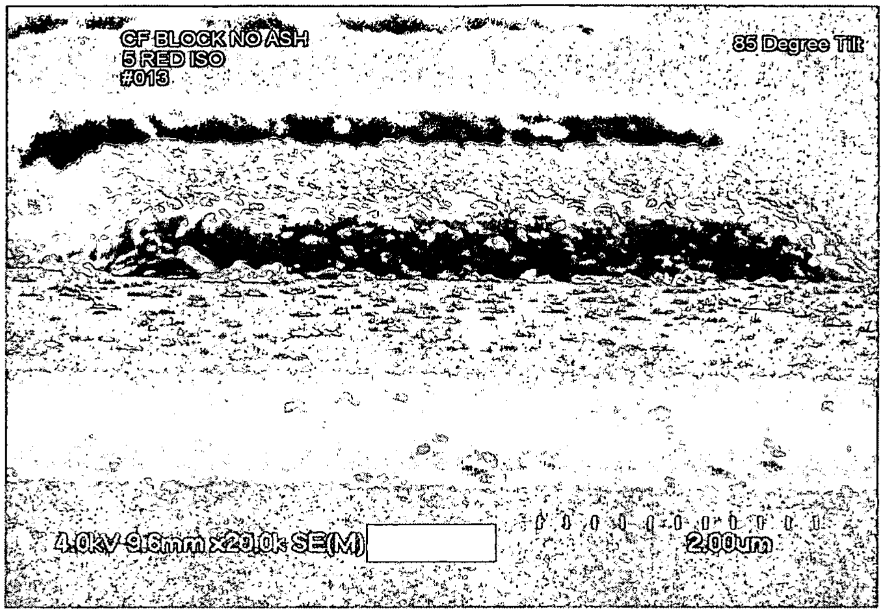

Figure 7: Red resist after blue and green pattern and hard bake.
(Note the proximity of the Kerosene stack edge.)

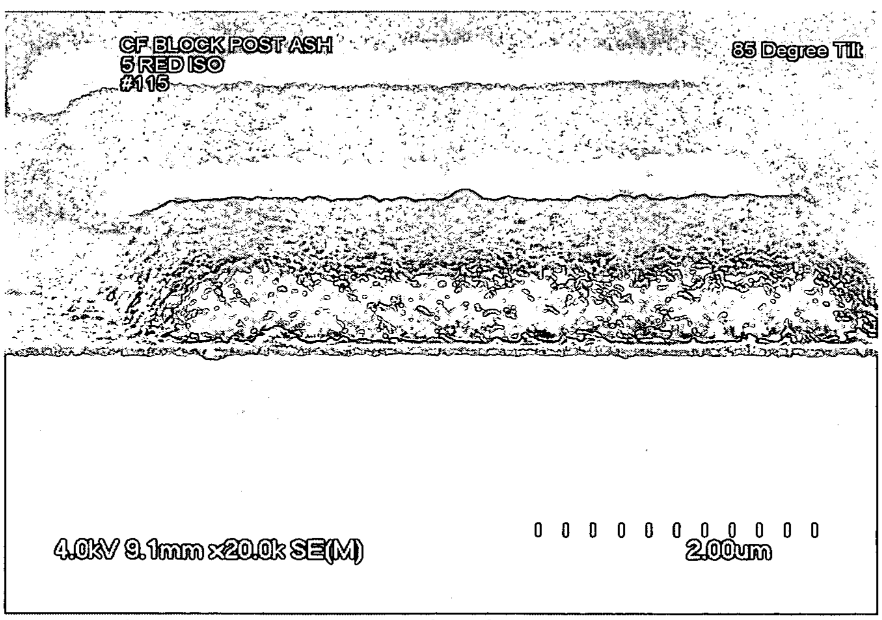

Figure 8: Red resist after final BARC removal ash.